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IS 10189-2-1 (1993): Industrial process control values,  
Part 2: Flow capacity, Section 1: Sizing equations for  
incompressible fluid flow under installed conditions  
(Superseding of IS 10189-2-1:1992 [ETD 18: Industrial  
Process Measurement and Control])

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अनुभाग 1 संस्थापित दशाओं के अंतर्गत असंवीक्ष्य तरल प्रवाह  
के लिए साइज निर्धारित करने के समीकरण

*Indian Standard*

INDUSTRIAL PROCESS CONTROL VALVES

PART 2 FLOW CAPACITY

Section 1 Sizing Equations for Incompressible Fluid Flow  
Under Installed Conditions

UDC 621·646·2 : 65·011·56 : 621-5

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BUREAU OF INDIAN STANDARDS  
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG  
NEW DELHI 110002

## FOREWORD

This Indian Standard ( Part 2/Sec 1 ) was adopted by the Bureau of Indian Standards, after the draft finalized by the Industrial Process Measurement and Control Sectional Committee had been approved by the Electrotechnical Division Council.

In many industrial applications, reducers or other fittings are attached to the control valves. The effect of these types of fittings on the nominal flow coefficient of the control valve is usually not negligible. It is therefore necessary to introduce a correction factor. Additional factors are introduced to take account of the fluid property characteristics that influence the flow capacity of a control valve.

This series of Indian Standard on Industrial Process Control Valves is being printed in several parts. Following parts have so far been printed:

- a) IS 10189 ( Part 1 ) : 1982 Industrial process control valves : Part 1 General requirements and tests; and
- b) IS 10189 ( Part 2/Sec 2 ) : 1992 Industrial process control valves: Part 2 Flow capacity, Section 2 Sizing equations for compressible fluid flow under installed conditions.

While preparing this standard assistance has been derived from IEC Pub 534 : 2 : 1978 'Industrial process control valves: Part 2 Flow capacity, Section 1 Sizing equations for incompressible fluid flow under installed conditions' issued by the International Electrotechnical Commission ( IEC ).

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

# Indian Standard

## INDUSTRIAL PROCESS CONTROL VALVES

### PART 2 FLOW CAPACITY

#### Section 1 Sizing Equations for Incompressible Fluid Flow Under Installed Conditions

##### **1 SCOPE**

**1.1** This standard ( Part 2/Sec 1 ), gives the method for determination of flow capacity for incompressible fluid in industrial process control valves.

**1.2** The equations presented in this standard are based on the Bernoulli equation for Newtonian incompressible fluids. They are not intended for use when non-Newtonian fluids, fluid mixtures, slurries, or liquid-solid conveyance systems are encountered.

##### **2 REFERENCE**

IS 10189 (Part 1) : 1982 'Specification for industrial process control valves : Part 1 General requirements and tests', is a necessary adjunct to this standard.

##### **3 DEFINITIONS**

For the purpose of this standard, the definition given in 2 of IS 10189 (Part 1) : 1982 shall apply, in

addition to the following.

##### **3.1 Choked Flow**

A limiting, or maximum flow condition that occurs as a result of vaporization of the liquid flowing within the valve.

NOTE — With fixed inlet (upstream) conditions, it is manifested by the failure of increasing pressure differential to produce further increases in the flow rate. Choked flow will be accompanied by either cavitation or flashing. If the downstream pressure is greater than the liquid vapour pressure, cavitation occurs. Flashing occurs if the downstream pressure is equal to or less than the liquid vapour pressure.

##### **3.2 Fitting**

Any device such as a reducer, expander, elbow, T-piece, or bend, which is attached directly to a control valve.

##### **4 NOMENCLATURE**

<i>Symbols</i>	<i>Description</i>	<i>Unit</i>
<i>C</i>	Flow coefficient ( $A_v, K_v, C_v$ )	Various [see IS 10189 (Part 1) : 1982]
<i>d</i>	Nominal valve size	mm
<i>D</i>	Internal diameter of the piping	mm
<i>F<sub>d</sub></i>	Valve style modifier	Dimensionless
<i>F<sub>F</sub></i>	Liquid critical pressure ratio factor	Dimensionless
<i>F<sub>L</sub></i>	Liquid pressure recovery factor of a control valve without attached fittings	Dimensionless
<i>F<sub>LP</sub></i>	Combined liquid pressure recovery factor and piping geometry factor of a control valve with attached fittings	Dimensionless
<i>F<sub>P</sub></i>	Piping geometry factor	Dimensionless
<i>F<sub>R</sub></i>	Reynolds number factor	Dimensionless
<i>N<sub>1</sub>, N<sub>2</sub>, N<sub>4</sub></i>	Numerical constants	Various (see Note 1)
<i>P<sub>e</sub></i>	Absolute thermodynamic critical pressure	kPa or bar (see Note 2)
<i>P<sub>v</sub></i>	Absolute vapour pressure of the liquid at inlet temperature	kPa or bar
<i>p<sub>1</sub></i>	Inlet absolute pressure measured at the upstream pressure tap	kPa or bar
<i>p<sub>2</sub></i>	Outlet absolute pressure measured at the downstream pressure tap	kPa or bar
<i>Δp</i>	Differential pressure between upstream and downstream pressure taps ( $p_1 - p_2$ )	kPa or bar
<i>Δp<sub>max (L)</sub></i>	Maximum allowable pressure differential for control valve sizing purposes without attached fittings	kPa or bar

Symbols	Description	Unit
$\Delta p_{\max}(\text{LP})$	Maximum allowable pressure differential for control valve sizing purposes with attached fittings	kPa or bar
$Q$	Volumetric flow rate	$\text{m}^3/\text{h}$
$Q_{\max(L)}$	Maximum volumetric flow rate in choked conditions without attached fittings	$\text{m}^3/\text{h}$
$Q_{\max}(\text{LP})$	Maximum volumetric flow rate in choked conditions without attached fittings	$\text{m}^3/\text{h}$
$Re_v$	Valve Reynolds number	Dimensionless
$\xi$	Head loss coefficient of a reducer or expander	Dimensionless
$\nu$	Kinematic viscosity (in centistokes)	$10^{-6} \text{ m}^2/\text{s}$ (see Note 3)
$\rho/\rho_o$	Relative density ( $\rho/\rho_o = 1.0$ for water at $15.5^\circ \text{C}$ )	Dimensionless

NOTES

- To determine the units for the numerical constants, dimensional analysis may be performed on equations (1), (9), and (14) using the units given in Table 1.
- 1 bar =  $10^5 \text{ Pa}$ .
- 1 centistoke =  $10^{-6} \text{ m}^2/\text{s}$ .

## 5 INSTALLATION

**5.1** In sizing control valves, using the relationships presented herein, the flow coefficients calculated are assumed to include all head losses between pressure taps located as shown in Fig. 1. It should be noted that the locations of the upstream and downstream pressure taps have been fixed at the outer limits shown in Part 1 of this standard (Fig. 3). These flow coefficients shall normally be compared with those listed in valve manufacturers' literature which also includes all head losses from two pipe diameters upstream through six diameter downstream of the control valve.

**5.2** For sizing purposes, a maximum allowable pressure differential has been introduced to identify choked flow.

## 6 GENERAL SIZING EQUATIONS

### 6.1 Non-choked Flow

The equation for the flow rate of a single Newtonian liquid through a control valve when operating under non-choked conditions is derived from the basic formula as given in 2.3 of Part 1 of this standard. The flow

rate shall be calculated as follows:

$$Q = N_1 \cdot F_p \cdot F_R \cdot C \sqrt{\frac{\Delta p}{\rho/\rho_o}} \quad (1)$$

Hence, the flow coefficient  $C$  (valve sizing coefficient) shall be determined by:

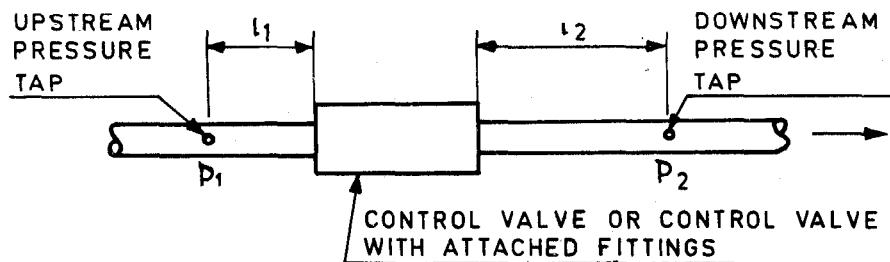
$$C = \frac{Q}{N_1 \cdot F_p \cdot F_R} \sqrt{\frac{\rho/\rho_o}{\Delta p}} \quad (2)$$

NOTE —  $F_p$  is unity when the control valve is installed without attached fittings.  $F_R$  will be unity when turbulent flow conditions exist. See 7.1 and 7.2 for determination of these factors.  $N_1$ , the numerical constant, depends on the units used in the general sizing equation and the type of flow coefficients  $A_v$ ,  $K_v$ , or  $C_v$ . Values for  $N_1$  are given in Table 1.

### 6.2 Choked Flow

#### 6.2.1 Choked Flow (Without Attached Fittings)

The maximum rate at which flow will pass through a control valve at choked flow conditions when installed



$l_1 = 2$  Nominal pipe diameters

$l_2 = 6$  Nominal pipe diameters

FIG. 1 PRESSURE TAP LOCATIONS

without attached fittings shall be calculated as follows:

$$Q_{\max(L)} = N_1 \cdot F_L \cdot F_R \cdot C \sqrt{\frac{p_1 - F_F p_v}{\rho/\rho_o}} \quad (3)$$

Hence :

$$C = \frac{Q_{\max(L)}}{N_1 \cdot F_L \cdot F_R} \sqrt{\frac{\rho/\rho_o}{p_1 - F_F p_v}} \quad (4)$$

NOTE — The maximum allowable pressure differential for control valve sizing purposes (that is, the minimum pressure differential at which the maximum flow rate occurs) with the control valve installed without attached fittings may be calculated as follows:

$$\Delta p_{\max(L)} = F_L^2 (p_1 - F_F p_v) \quad (5)$$

### 6.2.2 Choked Flow (With Attached Fittings)

The maximum rate at which flow will pass through a control valve when installed with attached fittings shall be calculated as follows:

$$Q_{\max(LP)} = N_1 \cdot F_{LP} \cdot F_R \cdot C \sqrt{\frac{p_1 - F_F p_v}{\rho/\rho_o}} \quad (6)$$

Hence:

$$C = \frac{Q_{\max(LP)}}{N_1 \cdot F_{LP} \cdot F_R} \sqrt{\frac{\rho/\rho_o}{p_1 - F_F p_v}} \quad (7)$$

NOTE — The maximum allowable pressure differential for control valve sizing purposes (that is, the minimum pressure differential at which the maximum flow rate occurs) with the control valve installed with attached fittings may be calculated as follows:

$$\Delta p_{\max(LP)} = \left[ \frac{F_{LP}}{F_P} \right]^2 (p_1 - F_F p_v) \quad (8)$$

## 7 DETERMINATION OF CORRECTION FACTORS

### 7.1 Piping Geometry Factor $F_p$

$F_p$ , the piping geometry factor, is necessary to account for fittings attached upstream and/or downstream to a control valve body. The  $F_p$  factor is the ratio of the flow rate through a control valve installed with attached fittings to the flow rate that would result if the control valve were installed without attached fittings and tested under identical conditions which will not produce choked flow in either installation (see Fig. 1). To meet a maximum permissible deviation of  $\pm 5$  percent, the  $F_p$  factor shall be determined by test. The pressure differential shall be limited to values such that no choking of the flow occurs.

When estimated values are permissible, the following equation may be used:

$$F_p = \frac{1}{\sqrt{1 + \frac{\Sigma \zeta}{N_2} \left( \frac{C}{d} \right)^2}} \quad (9)$$

NOTE — Values for  $N_2$  are given in Table 1.

In this equation, the factor  $\Sigma \zeta$  is the algebraic sum of all the effective velocity head coefficients of all fittings attached to the control valve. The velocity head coefficient of the control valve itself is not included.

$$\Sigma \zeta = \zeta_1 + \zeta_2 + \zeta_{B1} - \zeta_{B2} \quad (10)$$

where:

$\zeta_1$  = upstream resistance coefficient,

$\zeta_2$  = downstream resistance coefficient,

$\zeta_{B1}$  = inlet Bernoulli coefficient, and

$\zeta_{B2}$  = outlet Bernoulli coefficient.

When the diameters of inlet and outlet fittings are identical,  $\zeta_{B1} = \zeta_{B2}$  and drop out of the equation. In those cases in which the piping diameters approaching and leaving the control valves are different, the  $\zeta_B$  coefficients are calculated as follows:

$$\zeta_B = 1 - \left( \frac{d}{D} \right)^4$$

If the inlet and outlet fittings are short-length, commercially available, concentric reducers, the  $\zeta_1$  and  $\zeta_2$  coefficients may be approximated as follows :

$$\text{Inlet reducer only } \zeta_1 = 0.5 \left[ 1 - \left( \frac{d}{D} \right)^2 \right] \quad (11)$$

$$\text{Outlet reducer (expander) only } \zeta_2 = 1.0 \left[ 1 - \left( \frac{d}{D} \right)^2 \right] \quad (12)$$

Inlet and outlet reducers of equal size :

$$\zeta_1 + \zeta_2 = 1.5 \left[ 1 - \left( \frac{d}{D} \right)^2 \right] \quad (13)$$

The  $F_p$  values calculated with the above  $\zeta$  factors generally lead to selection of valve capacities slightly larger than required. This calculation require iteration.

When the inlet and oulet fittings are other than those described above, the resistance coefficients,  $\zeta_1$  and  $\zeta_2$ , must be obtained by test since they are not readily available.

### 7.2 Reynolds Number Factor $F_R$

$F_R$ , the Reynolds number factor, is required when non-turbulent flow conditions are established through a control valve because of a low pressure differential, a high viscosity fluid, a very small flow coefficient, or a combination thereof.

The  $F_R$  factor is determined by dividing the flow coefficient when non-turbulent flow conditions exist by the flow coefficient measured in the same installation under turbulent conditions.

If no test results are available,  $F_R$  may be determined from the curve given in Fig. 2, using a valve Reynolds number calculated from the following equations:

$$Re_v = \frac{N_4 \cdot F_d \cdot Q}{v [F_p \cdot F_L \cdot C]^{\frac{1}{2}}} \cdot \left[ \frac{F_p^2 \cdot F_L^2 \cdot C^2}{N_2 \cdot D^4} + 1 \right]^{\frac{1}{4}} \quad (14)$$

This calculation will require iteration.

The bracketed quantity in the above equation accounts for the "velocity of approach". Except for wide-open ball or butterfly valves, this refinement has only a slight effect on the  $Re_v$  calculation and can generally be taken as unity.

NOTE — Values for  $N_2$  and  $N_4$  are listed in Table 1.

Values for  $F_d$  are:

- 0.7 for control valves with two parallel flow paths such as double-ported globe and butterfly valves; and
- 1.0 for V-notch, ball, and single-ported globe valves. Values for  $F_d$  for other valve styles are not known at this time.

### 7.3 Liquid Pressure Recovery Factors

#### 7.3.1 Liquid Pressure Recovery Factor Without Attached Fitting $F_L$

$F_L$  is the liquid pressure recovery factor of the valve without attached fittings. This factor accounts for the influence of the valve internal geometry on the valve capacity at choked flow. It is defined as the ratio of the actual maximum flow rate under choked flow conditions to a theoretical, non-choked flow rate which would be calculated if the pressure differential used was the difference between the valve inlet pressure and the apparent "vena contracta" pressure at choked flow conditions.

Using water between 5°C and 40°C as specified in the test procedure, see IS 10189 (Part 1) : 1982,  $F_L$  is

calculated from test data using the following equation:

$$F_L = \frac{Q_{\max(L)}}{N_1 \cdot C} \sqrt{\frac{1}{p_1 - 0.96 p_v}} \quad (15)$$

#### 7.3.2 Combined Liquid Pressure Recovery Factor and Piping Geometry Factor with Attached Fittings $F_{LP}$

$F_{LP}$  is the combined liquid pressure recovery factor and piping geometry factor for a control valve installed with attached fittings. It is obtained in the same manner as  $F_L$ .

From test data where the fluid is water between 5°C and 40°C,  $F_{LP}$  is calculated using the following equation:

$$F_{LP} = \frac{Q_{\max(LP)}}{N_1 \cdot C} \sqrt{\frac{1}{p_1 - 0.96 p_v}} \quad (16)$$

To meet a maximum permissible deviation of  $\pm 5$  percent,  $F_{LP}$  must be determined by testing. When estimated values are permissible, reasonable accuracy may be obtained by use of the following equation:

$$F_{LP} = \frac{F_L}{\sqrt{1 + \frac{F_L^2}{N_2} (\sum \zeta_1) \left(\frac{C}{d^2}\right)^2}} \quad (17)$$

Here  $\sum \zeta_1$  is the velocity head coefficient,  $\zeta_1 + \zeta_{BL}$ , of the fitting attached upstream of the valve as measured

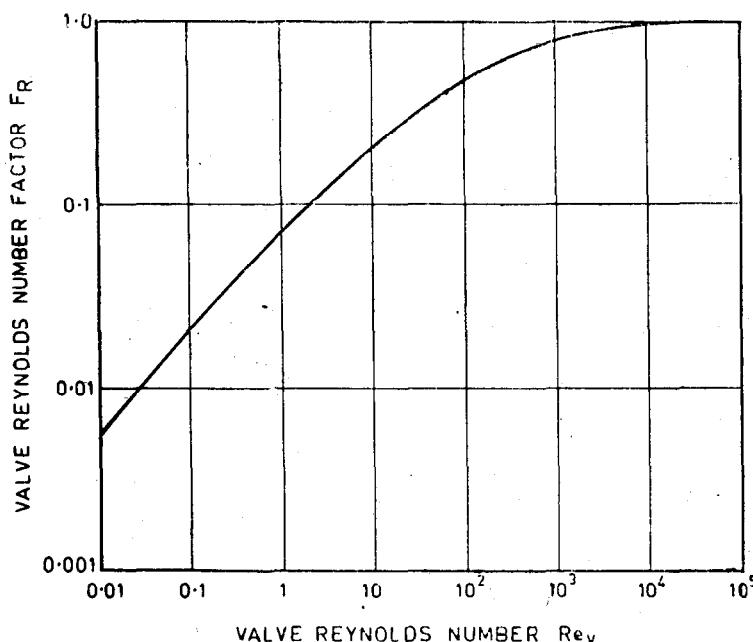


FIG. 2 REYNOLDS NUMBER FACTOR  $F_R$  FOR SIZING A CONTROL VALVE

between the upstream pressure tap and the control valve body inlet. The effect of a fitting ahead of a valve may produce sizing errors greater than 5 percent.

#### 7.4 Liquid Critical Pressure Ratio Factor $F_F$

$F_F$  is the liquid critical pressure ratio factor. This factor is the ratio of the apparent "vena contracta" pressure at choked flow conditions to the vapour pressure of the

liquid at inlet temperature. At vapour pressures near zero, this factor is 0.96.

Values of  $F_F$  may be determined from the curve given in Fig. 3, or approximated from the following equation:

$$F_F = 0.96 - 0.28 \sqrt{\frac{P_v}{P_c}} \quad (18)$$

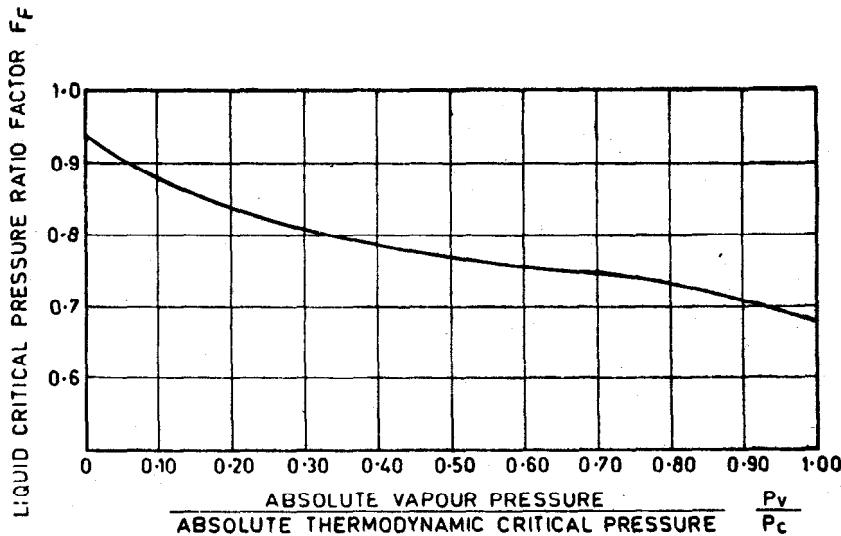


FIG. 3 LIQUID CRITICAL PRESSURE RATIO FACTOR  $F_F$

Table 1 Numerical Constants  $N$   
(Clauses 4, 6.1, 7.1 and 7.2)

Constant	Flow coefficient $C$			Formulae units			
	$A_v$	$K_v$	$C_v$	$Q$	$d, D$	$p_1, p_2, p_v, \Delta p$	$\rho$
$N_1$	$3.6 \times 10^3$	$1 \times 10^{-1}$	$8.65 \times 10^{-2}$	$m^3/h$	mm	kPa	$kg/m^3$
	$3.6 \times 10^4$	$1 \times 10^0$	$8.65 \times 10^{-1}$	$m^3/h$	mm	bar	$kg/m^3$
$N_2$	$1.23 \times 10^{-12}$	$1.6 \times 10^{-3}$	$2.14 \times 10^{-3}$	—	mm	—	—
$N_4$	$3.72 \times 10^2$	$7.07 \times 10^4$	$7.6 \times 10^4$	$m^3/h$	—	—	—

NOTE — Use of the numerical constants provided in this table together with the practical metric units specified in the table will yield flow coefficients in the units in which they are defined.

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